INVISIBLE HIGGS IN LARGE EXTRA DIMENSION MODELS

DANIELE DOMINICI
Dipartimento di Fisica, Università di Firenze, I-50019 Sesto F., Italy
I.N.F.N., Sezione di Firenze, I-50019 Sesto F., Italy

In large extra dimension models the presence of an interaction between the Ricci scalar curvature and the Higgs doublet of the Standard Model can give rise to an invisible decay of the Higgs to Kaluza Klein graviscalars. The corresponding invisible width can cause a suppression of the LHC rates of a light Higgs in the visible channels below 5σ in some regions of the parameter space of the model. However in such regions the Higgs can be discovered through its invisible decay. The combination of the measurements done at the LHC and the LC can determine to some accuracy the parameters of the model.

1 Introduction

In large extra dimension models the interaction between the Higgs doublet field H and the Ricci scalar curvature R of the induced 4-dimensional metric g_{ind}, given by $S = -\xi \int d^4x \sqrt{g_{ind}} R(g_{ind}) H^\dagger H$, after the usual shift $H = (\frac{v+h}{\sqrt{2}}, 0)$, leads to the following mixing term [1]

$$\mathcal{L}_{\rm mix} = \epsilon h \sum_{\vec{n}>0} s_{\vec{n}} \tag{1}$$

with

$$\epsilon = -\frac{2\sqrt{2}}{\overline{M}_{Pl}} \xi v m_h^2 \sqrt{\frac{3(\delta-1)}{\delta+2}}\,. \tag{2}$$

Above, $\overline{M}_{Pl} = (8\pi G_N)^{-1/2}$ is the reduced Planck mass, δ is the number of extra dimensions, ξ is a dimensionless parameter and $s_{\vec{n}}$ is a graviscalar KK excitation with mass $m_{\vec{n}} = 2\pi|\vec{n}|/L$, L being the size of each of the extra dimensions. This mixing generates an oscillation of the Higgs itself into the closest Kaluza Klein graviscalar levels and therefore an invisible decay for the Higgs. The corresponding width can be calculated by extracting the imaginary part of the Higgs self energy contribution due to the mixing in eq. (1) [1,2] (see also [3]) and is given by

$$\begin{aligned}\Gamma_{h\to inv} &= \frac{\pi}{2} m_h^{\delta-3} \epsilon^2 \frac{\overline{M}_{Pl}^2}{M_D^{2+\delta}} \frac{\pi^{\delta/2}}{\Gamma(\delta/2)} \\ &\sim (16\,MeV) 20^{2-\delta} \xi^2 S_{\delta-1} \frac{3(\delta-1)}{\delta+2} \left(\frac{m_h}{150\,GeV}\right)^{1+\delta} \left(\frac{3\,TeV}{M_D}\right)^{2+\delta}\end{aligned} \tag{3}$$

2 Detecting the Higgs at the LHC and LC

Fig. 1 shows that the branching ratio of the Higgs into invisible states can be substantial for M_D values in the TeV range both when $m_h = 120$ GeV (upper part), therefore below the WW threshold, and when $m_h = 237$ GeV (lower part), a value greater than the WW threshold and corresponding to the 95% CL limit from LEP data with $m_t = 178$ GeV. As a consequence this invisible width causes a significant suppression of the LHC Higgs rate in the standard visible channels and for any given value of the Higgs boson mass, there is a considerable parameter space region where the invisible decay width of the Higgs boson could be the first measured phenomenological effect from extra dimensions. This is exemplified in Fig. 2 for $m_h = 120$ GeV, $\delta = 2$ (left), 4 (right). In the green (light grey) region the Higgs signal in standard channels drops below the 5 σ threshold with 100 fb^{-1} of LHC data. But in the area above the bold blue line the LHC search for invisible decays in the fusion channel yields a signal with an estimated significance exceeding 5 σ. In conclusion, whenever the Higgs boson sensitivity is lost due to the suppression of the canonical decay modes, the invisible rate is large enough to still ensure detection through the WW fusion channel.

Fig. 3 shows 95% CL contours for determination of the ADD parameters, M_D, ξ and δ assuming $m_h = 120$ GeV obtained by combining LHC and LC signal in visible and invisible channels and LC $\gamma + \not{E}_T$ cross section measurements at two different energies. The plots are all obtained for $\delta = 2$ and $\xi = 0.5$, assuming $L = 100$ fb^{-1} at the LHC, $\sqrt{s} = 350$ GeV Higgs measurements at the LC, $\sqrt{s} = 500$ GeV and $\sqrt{s} = 1000$ GeV $\gamma + \not{E}_T$ measurements at the LC with $L = 1000$ fb^{-1} and $L = 2000$ fb^{-1} at the two respective energies.

In conclusion the accuracy of the determination of the three parameters of the model is relatively good unless both δ and M_D are large or $\xi << 1$.

Acknowledgments

I would like to thank M. Battaglia, J. Gunion and J. Wells for their collaboration on the topics discussed in this talk.

References

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3. M. Battaglia, D. Dominici, J. F. Gunion and J. D. Wells, in B. C. Allanach *et al.* [Beyond the Standard Model Working Group Collaboration], hep-ph/0402295.

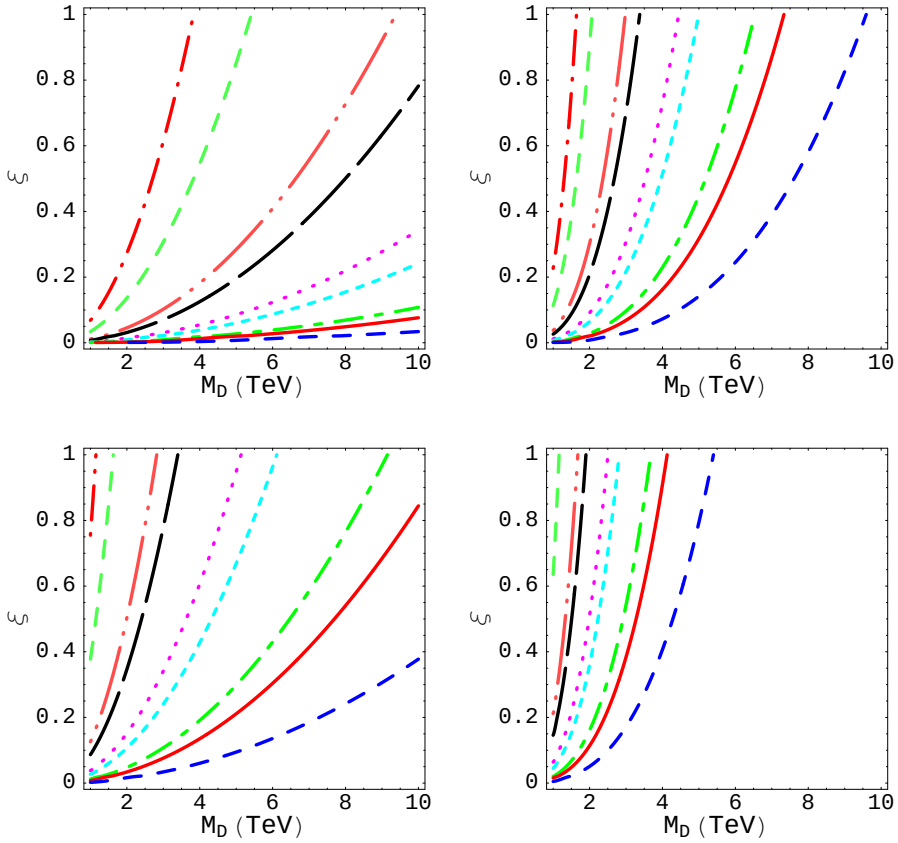

Figure 1: Contours of fixed $BR(h \to inv)$ in the M_D(TeV) – ξ parameter space for $\delta = 2$ (left) and $\delta = 4$ (right) in the upper part for $m_h = 120$ GeV and in the lower part for $m_h = 237$ GeV. In order of increasing ξ values, the contours correspond to: 0.0001 (large blue dashes), 0.0005 (solid red line), 0.001 (green long dash – short dash line), 0.005 (short cyan dashes), 0.01 (purple dots), 0.05 (long black dashes), 0.1 (chartreuse long dashes with double dots), 0.5 (green dashes), and 0.85 (red long dash, short dot line at high ξ and low M_D)

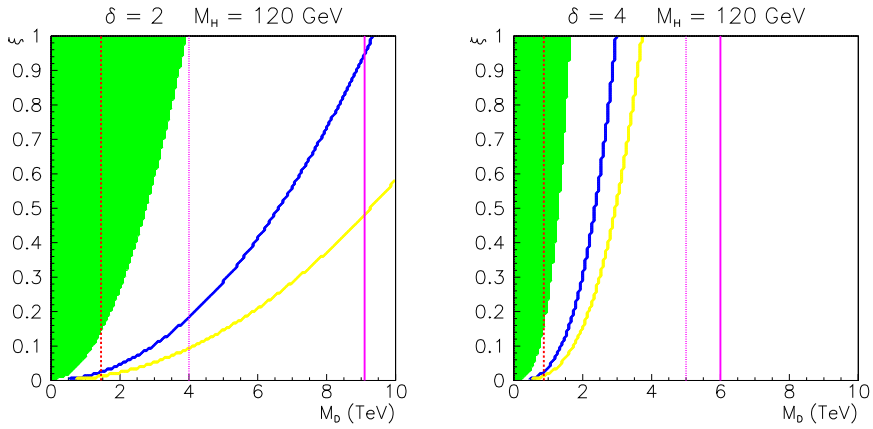

Figure 2: Invisible decay width effects for $m_h = 120$ GeV, δ: 2 (left), 4 (right). The green (grey) regions indicate where the Higgs signal at the LHC drops below the 5 σ threshold for 100 fb^{-1}. The regions above the blue (bold) line are where the LHC invisible Higgs signal in the WW-fusion channel exceeds 5 σ significance. The solid vertical line shows the upper limit on M_D which can be probed at the 5 σ level by the analysis of jets/γ with missing energy at the LHC. The middle dotted vertical line shows the value of M_D below which the theoretical computation at the LHC is ambiguous. The dashed vertical line at the lowest M_D value is the 95% CL lower limit coming from Tevatron and LEP/LEP2. The regions above the yellow (light grey) line are where the LC invisible Higgs signal will exceed 5 σ.

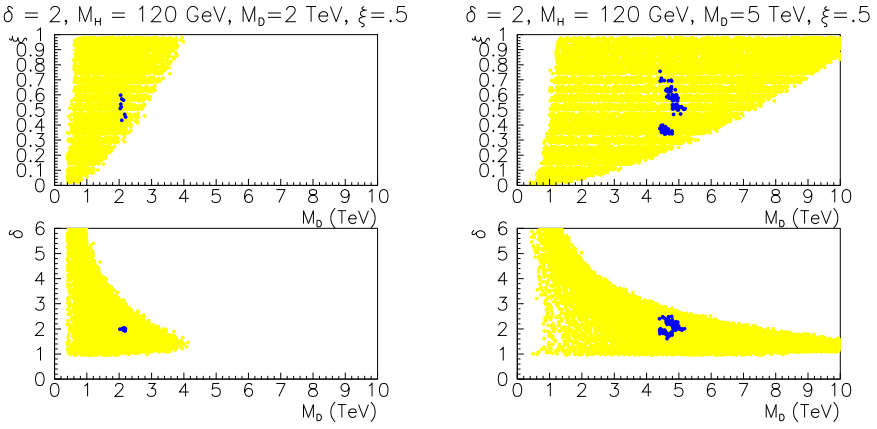

Figure 3: 95% CL contours for the determination of the ADD parameters, assuming $m_h = 120$ GeV. The larger light grey (yellow) regions are the 95% CL regions using only $\Delta\chi^2(LHC)$, the smaller dark grey (blue) regions using $\Delta\chi^2(LHC + LC)$.